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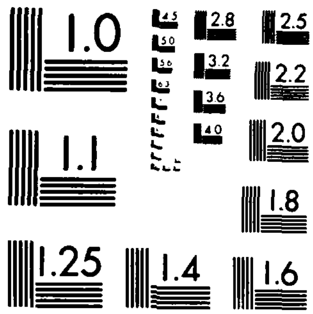

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ROYAL SIGNALS & RADAR ESTABLISHMENT

IMAGE UNDERSTANDING FOR MILITARY SYSTEMS: A DISCUSSION OF THE WAY FORWARD FOR PRIP RESEARCH IN BRITAIN

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PROCUREMENT EXECUTIVE,
MINISTRY OF DEFENCE,
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ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 3560

Title: IMAGE UNDERSTANDING FOR MILITARY SYSTEMS: A DISCUSSION OF THE WAY FORWARD FOR PRIP RESEARCH IN BRITAIN

Author: A C Sleigh

Date: February 1983

SUMMARY

This note is closely based on a presentation I made to the SERC Research Area Review Meeting at the Rutherford Appleton Laboratory on 14 December 1982. It is concerned with the military interest in image processing, and includes my view of where image processing research should be directed in the future. It was presented against a background of discussion on how Pattern Recognition and Image Processing (PRIP) research should be co-ordinated in the future, and whether there is a case to build up a number of 'Centres of Excellence' with the resources and multidisiplinary teams needed to make progress in this field. Since much of its content has a wider interest, it has been published as an RSRE Memorandum.

Any views expressed are those of the author and do not necessarily represent those of the Department

IMAGE UNDERSTANDING TECHNIQUES FOR MILITARY SYSTEMS:
A DISCUSSION OF THE WAY FORWARD FOR PRIP RESEARCH IN BRITAIN

A C Sleigh

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1. INTRODUCTION

The presentation was divided into three parts: an introduction to the military interest in PRIP; some examples of military systms which will make significant use of PRIP; and a discussion of what form image processing systems might look like, including what 'tools' they might need.

The words "Pattern Recognition and Image Processing" are often used indiscriminately to describe widely differing work, from image enhancement, which re-arranges information to be more easily interpreted by human observers, to earth resource studies which are trying to, say, define axes in a multi-dimensional image which correspond to diseased wheat, to scene understanding systems which can interpret various pieces of information and automatically initiate a response. These activities are very different in the type of techniques they use. Image enhancement has more to do with the limitations of displays and the human visual system, resource analysis is mainly concerned with linear transforms and simple classifiers which draw class boundaries in a hyper-space, while image understanding is mainly concerned with representing the constraints which operate in the real world and applying these in a manageable computational environment. One cannot expect any sense to result from lumping all these fields together, and at the moment ignorance of these differences is one of the biggest stumbling blocks in agreeing a policy on future PRIP research.

In the rest of this paper I am concerned exclusively with techniques which fall into the image understanding category (Figure 1), particularly those which might be applied in the late 80's, which will be most influenced by decisions made today. Figure 2 further defines the scope. In particular I am not concerned with problems which can be solved using decision theoretic methods only. These methods are widely used and their performance and limitations are well understood. They figure in many current military research programmes, and are a standard tool accessible to non-specialists. There are standard libraries of statistical algorithms (eg ALPARS); and military and commercial exploitation (for example in OCR and target recognition) is successful and not in need of significant intervention by SERC.

I make the assumption that progress in PRIP will need advances in our fundamental understanding of processing systems, and not merely new (and probably more powerful) implementations of existing concepts. I emphasize the importance of advancing the state of the art in PRIP techniques; and how the philosophies of image understanding can advance hand in hand with developments in hardware, computer architectures, and firmware.

2. MILITARY INTEREST IN IMAGE UNDERSTANDING

Figure 3 states the two main reasons why image processing will play an increasingly important part in the future of Military systems: autonomous operation and the need to make greater use of the outputs from sensors.

For a multitude of reasons, fast reaction is becoming more important in

defence systems. This forces more of the decisions to be made without operator interaction: in many cases operator interaction will not be possible at all. Targetting, Command and Control need to make sense out of various disparate and possibly un-reliable sources, and will draw on the artificial intelligence techniques which will result from advanced image understanding research. These will pass control to autonomous systems which may have to select a target from rough instructions.

The trend in sensors is to produce more information than a man can assimilate, especially in a saturation attack or where he has other jobs to do, such as flying a helicopter. As equipment becomes more complicated it must take more responsibility for its own adjustment and operation. It must still be effective with a tired or undertrained operator. With few exceptions, we cannot expect much improvement in the performance of sensors in the future. Indeed, with the counter-measures likely by the 90's they may be a good deal less effective than they are today. The only available avenue for advance is to make greater use of the information being gathered and provide sensors with a greater intelligence.

In imaging systems the display is often a weak link which can be significantly improved by auto-cueing and option selection. Transferring pictures from place to place is an expensive activity, and there will be considerable pressure to send coded information which will drastically reduce the bandwidths required. For example, sending a picture of a car needs the best part of a Mbyte; the words "Ford Cortina" use just a handful. These and many other examples illustrate the assertion that image processing is likely to be one of the most important techniques in the 80's and 90's for improving the cost effectiveness of defence systems. Lack of capability in this area will be very detrimental to the ability of military (and commercial) products to meet competitively the future requirements.

Figure 4 shows a typical military image processing situation. The output from the sensor may need to be manipulated and transformed to correct for defects and to put the output into a suitable processing space. This corrected image is interpreted and then compared with ground rules, a-priori information, some of which will be scenario dependent. This decision is then acted upon, pehaps after approval by a 'man in the loop'.

Figures 5 and 6 give three examples of image processing: a panoramic IR surveillance sensor, and autonomous missile, and an advanced radar. The latter also illustrates the relationship between mathematical methods, which tend to break down because the problem may be ill-formed, and intelligent guesses based on a-priori information which might have a good chance of getting the correct solution even when an unconstrained purely mathematical approach would 'blow up'. An intelligent guess is better than no deduction at all. Many might not consider this PRIP in a true sense, but I would not agree. It illustrates the generality image understanding methods are likely to have.

3. WHAT DIRECTION SHOULD IMAGE UNDERSTANDING RESEARCH BE TAKING?

3.1 Introduction to the Problems Image Understanding Must Solve

Let us say that there are two types of image understanding problem (Figure 7): simple problems where the dimensionality is small and there is a good training regime available; and more a general case where the dimensionality is large and training is poor, ie it is difficult or impossible to gather a large enough training set to establish decision boundaries with adequate precision. In the first simpler case, decision theoretic approaches will give an 'optimum' classification, at least when Gaussian statistics apply. As the dimensionality and number of classes increase the size of the training set grows explosively to the point where decision theoretic methods cannot work even given enormous computing power; it is clearly unsanitary to gather a training set of 10^{10} or more independent measurements.

What is needed to get around this problem is a way of constraining the problem sufficiently to get a solution. How this is best done is one of the great challenges facing science at the moment. It can be done by reducing the dimensionality, which implies some non-linear operation such as coding, eliminating unlikely or impossible solutions, for example by incorporating Newton's Laws or the rules that relate 3D objects to 2D views. It can also be done by model generation and testing where inductive methods dominate, or by special grammars which contain the constraints of the real world. It is most likely that this can only be solved by systems which have a considerable degree of internal structure: particular parts of the process will perform different specialized operations.

The progress in computing hardware and, of equal importance, computer architectures, will provide a significant increase in computing power over the next decade. You can argue about what gain will be achieved in terms of chip or wafer complexity, and what increases in efficiency and real estate utilization will come from architecture advances, but an increase in the 100-1000 region is not impossible. By the mid 90's the amount of computing power available to an image processing system will be so much greater that new approaches to the way image processing is performed will be necessary. We will need a new generation of researchers who have a good grasp of computer architectures, philosophy and mathematics, working in teams which comprise experts in each of these.

As the complexity of each 'chip' tends towards wafer size, the penalty of using a limited number of standard components will be severely felt, even if these are relatively general purpose, and the main advances are most likely to be made by teams with access to powerful CAD facilities who can fabricate large custom chips from well tried sub-modules. This approach will become the more important as getting data on and off the substrate and matching real to virtual machines assume a greater priority in the design. At the same time computer architecture will play a larger part in the concepts of image understanding, and the arguments for close association of algorithm, paradigm, computer, and chip development will strengthen. Image processing is very likely to be the biggest and most demanding user of VLSI in the future; the IP community has a responsibility to steer future chip development (Figure 8).

3.2 An Approach to Implementing Image Understanding

A theme which is explored by this paper is to define relatively independent "Functional Blocks" which can be configured into a complete system. Research can then be aimed at enhancing the performance of these Functional Blocks, which can be transportable either through the use of one from a number of suitable languages (eg Fortran, Pascal and Prolog) through a standard library, or eventually as ROM'S for commonly used machines or even as VLSI sub-masks in a chip CAD simulator. When considering this concept one must avoid being constrained by past difficulties in standardization. Software can be embodied into system generation procedures in very flexible ways, and technology has advanced to the point where hardware is designed using methods previously confined to software. Indeed the distinction between hardware and software is becoming increasingly academic, opening very powerful ways of incorporating systematic knowledge into CAD facilities.

Figure 9 shows how typical Functional Blocks might be arranged to form an image understanding system. Following attention direction, a portion of the scene is coded into a feature space by a variety of operators. These work over very local regions; they might use statistical feature classifiers, rule based or heuristic methods. The feature map represents a highly non-linear transform space with dimensions which represent, say, the "edginess" or "corneriness" of regions in the attention patch. In the classic Marr tradition, shape operators then scan this feature map and find more global properties such as rectangles, arcs, sticks, conic sections, etc. This process will necessarily have to make a number of alternative interpretations because of the ambiguities in the way features can be connected. To resolve these ambiguities these shapes are used as keywords to trigger an expert system which would contain a data base of possible objects. It can then ask questions of the feature map, or even of the original scene, until it has enough information to make a decision. This can be looked upon as interactively building a model of the scene using the ground rules contained in the expert system, and testing it against what is observed. The feature coding and the shape extraction form a deductive loop which drives the guesses made by the expert system; the expert system and model testing form and inductive loop which tries out these guesses.

Clearly this is one from many possible ways of carrying out image understanding. The point I make is its use of a number of distinct levels of operations and functional blocks which have wider application. If effective algorithms existed today it would be possible to try out such a configuration, see how it worked and improve its design. Unfortunately it is not yet possible to lay ones hand on robust feature coding algorithms; expert systems are mostly "hand crafted" and very difficult to train; and methods for representing shapes are very immature. Relaxation labelling is on a fairly firm theoretical footing, but applying it to model generation is not a straight forward step. The aims of those engaged in techniques research should be to bring these and other functional blocks to a configurable state, in an appropriate computer architecture(s). Figure 10 lists some other Functional Blocks which should be covered by a coherent image processing research programme.

3.3 List of Research Topics Important to Image Understanding

It is useful to discuss the areas of PRIP research against a background of broad topics. I have produced the following list of such topics to simplify discussion of image understanding, not necessarily as a guide to how research should eventually be coordinated.

a. Local Region Evaluation. This covers methods which categorize the properties around small portions of a scene including texture, movement, shape: ie low level sketch generators.

b. Propagation Methods. This is to do with associating and relating different parts of an image. It includes existing concepts of segmentation, region growing, and associating features like edges and corners to form higher level shapes. The rules of association will become quite complex, (eg would include 2D to 3D interpretations) and are likely to draw on the methods of topic d.

c. Cellular and Systolic approaches. These descendents of the "Perceptron" concept include associative memories, hierarchies of nodes with trainable regions of sensitivity in the planes below them, 'Wizard' machines, etc.

d. Artificial Intelligence using Knowledge Based approaches. Already a growth area, this is likely to be the core of any image understanding system. Expert systems appear to be essential at the higher levels of any PRIP system, but less obviously, they also have potential impact at lower levels.

e. Linguistic Methods. Success in the description of pictures by linguistic forms, which also conform to a grammar which somehow contain the constraints of the real world, would have great significance. In some respects this is an alternative to the use of Expert Systems.

f. Virtual Computing Machines and Languages. Much insight into the physics of information processing has been gained from the writing and implementation of computer languages. As well as providing the tools to execute image understanding, Computer Science must have a lot to say about the fundamental limitations and properties of information manipulation.

g. Hardware design. Includes implementing appropriate virtual machines efficiently, providing good image processing development systems, adapting concepts to fit well in VLSI, and also interacting with the other topics to ensure optimum use can be made of device performance.

h. Study of Complete Processing Systems. A natural part of the 'functional block' concept, an important area is determining how these interact as a system.

i. Comparisons with Biolgical Systems. There are several areas of interest, particularly the low level operation of biological vision, deductions about its overall structure, biochemical engineering, etc.

If this country could point to strong teams working in each of these topics, we would have the makings of a good image understanding programme. It is of concern that this is not the case: out of 245 entries in the "Pattern Recognition and Image Processing Review" recently produced by Dr J V Kittler of RAL, which lists all PRIP research in universities and SERC labs, only 31 fall into the topics defined above. Research in these topics must be strengthened as a matter of urgency, and equally important, made to inter-relate to provide the foundations for future PRIP systems.

4. CONCLUSIONS

It has been suggested that an initiative is needed to establish a strong research base in the UK to make sure we have the people and equipment to make the necessary impact. I stongly agree with this proposal. It should encompass the work at research establishments like RSRE and Rutherford Labs, the universities, and provide facilities and knowledge to industry. I am interested to see three things come about:

a. To see that research into new techniques is supported in a coordinated manner at the universities, so that at least the topics outlined in section 3.3 are being adequately pursued. When looked at as a whole, the long term research should form a coherent picture. The universities must accept that long term research needs to be planned around objectives, and not conducted around the 3 year PhD in an organisational vacuum. Correctly implemented, it should free university research from the often inappropriate alternative of linking their research to short term applied problems in order to gain funding.

b. There should be a number of 'Centres of Excellence' with teams large enough to be able to tackle the multi-disciplinary nature of this research with the appropriate hardware, which is too expensive to be proliferated throughout universities, MOD and Industry. These centres would form the meeting point for long term and applied research. It will be possible to formulate research programmes whose primary aim is to further the techniques base, independent of applications, but will be able to use the expertise developed and maintained by these programmes on appropriate applied work. That is, individuals will have a coordinated responsibility to advance techniques, but will regularly become involved with applications. This method of operation is impossible without the Centres of Excellence. Because of its association with sensors, computer devices/VLSI, and image understanding applied to systems, I argue that RSRE should be one of these centres. All PRIP researchers in universities, industry and government departments would presumably spend some of there time at one of these centres.

c. There is already a shortage of adequate under-graduate or post-graduate training in PRIP. The subject has so far not received the status or interest it deserves in universities, partly because of the Lighthill report which blighted work during the 70's. As image understanding assumes greater importance there will be a severe shortage of experienced graduates. Satisfying this requirement may in some sense in conflict with the Centres of Excellence idea, since it

tends to argue for setting up image processing departments in all the major universities. It is a conflict which must be correctly resolved, and not used as an argument against establishing 'Centres of Excellence'.

To bring these about will not be easy, especially in a timely manner. An attempt must be made if we are to be able to retain any Image Understanding research initiative in the UK.

Figure 11 lists a number of points I would like people to take away with them:

Image Processing is bound to become a vital technique in most future military systems (and many commercial applications as well).

The UK research into image processing techniques is in a poor state and has fallen behind other countries.

The multi-disciplinary nature of the subject, the need to achieve a good relationship between speculative and applied research, and the high cost of capital equipment, make the setting up of 'Centres of Excellence' paramount.

More emphasis must be given to teaching image understanding in universities as a legitimate multi-disciplinary field.

Is is possible to link long term research with a plan for providing a set functional blocks which will form the building bricks for applications work?

IMAGE ENHANCEMENT

LINEAR TRANSFORMS

IMAGE UNDERSTANDING

INVOLVE DIFFERENT TECHNIQUES AND SHOULD NOT BE TREATED AS ONE

THIS PAPER IS CONCERNED WITH IMAGE UNDERSTANDING

"IMAGE" MEANS SOME VECTOR REPRESENTING A SAMPLE, OR GROUP OF SAMPLES, FROM THE SYSTEMS'S SENSORS

"UNDERSTANDING" MEANS DECIDING WHAT ACTION IS MOST LIKELY TO ACHIEVE DESIRED RESULT

FIGURE 1

THIS PAPER WILL NOT INCLUDE PATTERN RECOGNITION PROBLEMS WHICH CAN BE TREATED BY FEATURE EXTRACTION AND STATISTICAL METHODS.

THESE ARE TAKEN TO BE WELL UNDERSTOOD AND THEIR MILITARY APPLICATION IS USUALLY CLASSIFIED.

THIS PAPER IS MAINLY CONCERNED WITH TECHNIQUES WHICH CAN BE APPLIED DURING THE NEXT 3-10 YEARS

AND ESPECIALLY HOW IP PHILOSOPHY, SOFTWARE FIRMWARE AND HARDWARE CAN EXPLOIT DEVICE PROGRESS WITH MAXIMUM EFFECT

FIGURE 2

WHY IS THERE MILITARY INTEREST IN IP

1 NEED FOR AUTONOMOUS OPERATION

- INCREASING EMPHASIS ON FAST REACTION SYSTEMS

- LARGER AMOUNT OF DATA PROVIDED BY SENSORS IS TOO GREAT TO BE PROCESSED BY MEN WITHOUT ASSISTANCE

- NEED TO REDUCE MANPOWER AND TRAINING

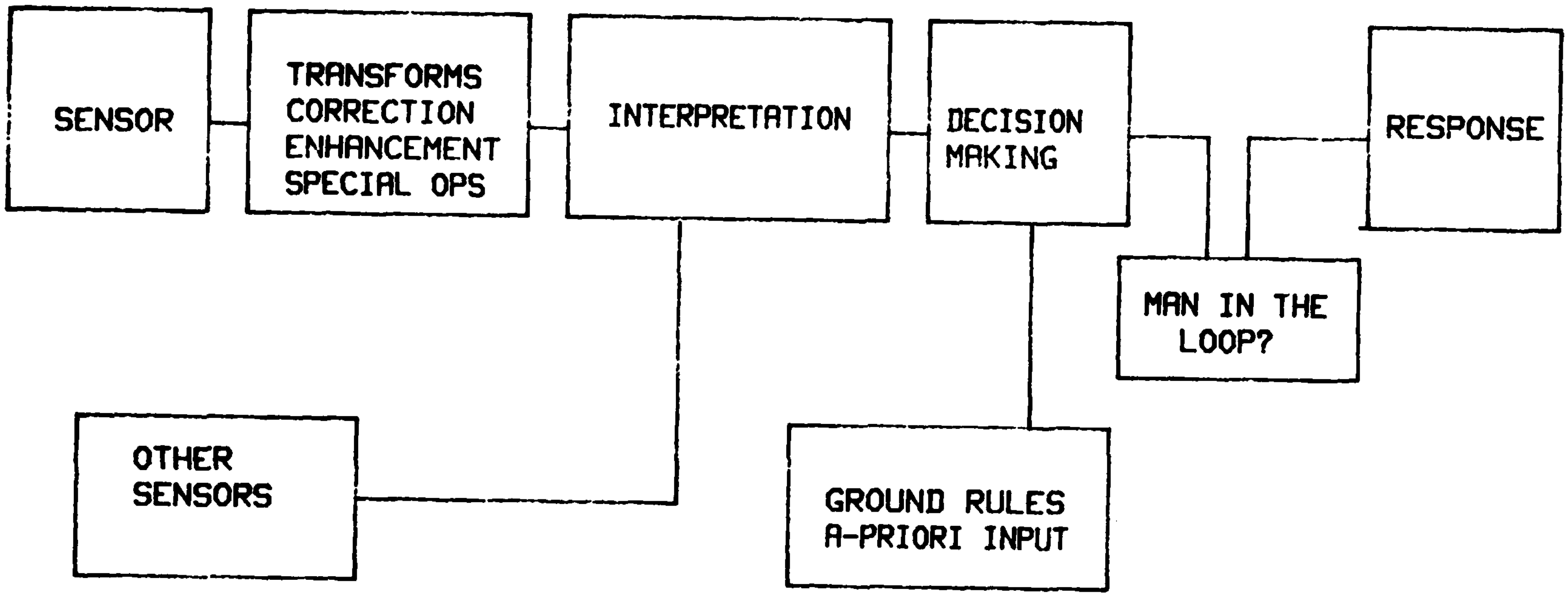
- COMMAND CONTROL AND COMMUNICATION SITUATION

2 NEED TO EXTRACT MORE INFORMATION FROM SENSORS

- MANY SENSORS (eg RADARS) HAVE POTENTIAL TO GIVE FAR MORE INFORMATION THAN CURENTLY EXTRACTED. "INTELLIGENCE" AND "EXPERIENCE" IS OFTEN NEEDED

- A MAJOR BOTTLENECK IS DISPLAYING INFORMATION TO THE OPERATOR. AUTO-CUEING OR OPTION CHOICE INCREASE EFFECTIVENESS.

FIGURE 3



TYPICAL MILITARY PROCESSING SYSTEM

FIGURE 4

EXAMPLES OF MILITARY IMAGE PROCESSING

PROCESSING FOR INFRARED SURVEILLANCE

PANORAMIC SENSOR GATHERING 10 MBYTES OF INFO/SEC.
SEVERE CLUTTER PROBLEM, VERY LOW FALSE ALARM RATE REQUIRED

AUTONOMOUS MISSILE

MUST RECOGNISE DESIRED TARGET IN CLUTTERED AND DECOYED BACKGROUND. CRUDE PERFORMANCE AVAILABLE TODAY; HOW CAN WE MAKE ROBUST AND CHEAP HOMING HEADS IN THE FUTURE?

FIGURE 5

EXAMPLES CONT. - RADAR IMAGING

ADVANCED RADAR MIGHT MEASURE RANGE, DOPPLER, RCS VS FREQ. ETC
LEADING TO PERHAPS A 10 DIMENSIONAL IMAGE SPACE

INVERSE MATRIX RECONSTRUCTION CAN BE USED
    BUT IS COMP. INEFFICIENT AND OFTEN ILL-FORMED
CONSTRAINING RULES CAN BE USED TO MAKE PROBLEM BETER FORMED
    BUT SUCCESS HAS SO FAR BEEN MINIMAL
INTELLIGENT GUESSES WITH ITERATED RE-INTERPRETATION
    NO KNOWN METHODS

FIGURE 6

THERE ARE TWO TYPES OF IP PROBLEM

1 SIMPLE PROBLEM: FEW CLASSES; GOOD TRAINING REGIME
DECISION THEORETIC APPROACHES ALWAYS WORK

2 OTHER PROBLEMS: MANY CLASSES; INADEQUATE TRAINING REGIME
DECISION THEORETIC METHODS CANNOT WORK

IE THE WHOLE QUESTION IS HOW TO CONSTRAIN PROBLEM

WHAT METHODS MIGHT BE USED?

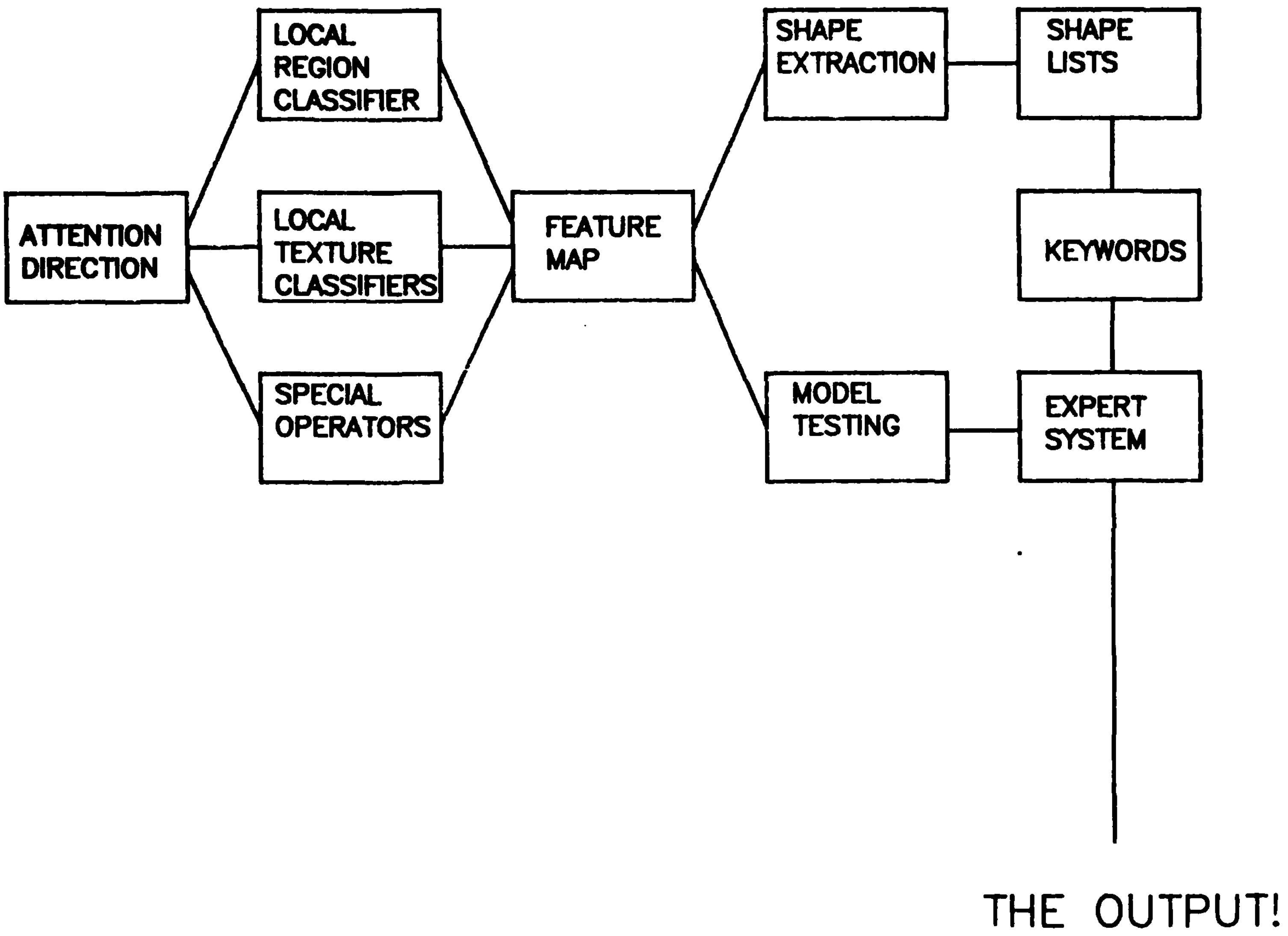
a REDUCING DIMENSIONALITY	EG CODING BY LOCAL FEATURES
b CONSTRAINING ALLOWED SOLUTIONS	EG LAWS OF PHYSICS
c ASSOCIATIVE MEMORY	EG KEYWORD ORGANISATION
d MODEL GENERATION AND TESTING	EG EXPERT SYSTEMS?

FIGURE 7

DIGRESSION ON HARDWARE

- DEVELOPMENT OF NEW ARCHITECTURES MAY BECOME MOST IMPORTANT ASPECT. MACHINE CANNOT BE DEVORCED FROM PHILOSOPHY
- GOOD COMPUTER AIDED DESIGN IS ESSENTIAL AS WE TEND TOWARDS WAFER SIZED CHIPS. WITHOUT THIS WE WILL BE LIMITED TO A SMALL NUMBER OF "STANDARD" CHIPS
- GOOD HIGH LEVEL LANGUAGES WHICH ARE TRANSPARENT TO ANY MACHINE ARCHITECTURE ARE A NECESSARY COROLLARY TO THIS
- IMAGE PROCESSING IS LIKELY TO BE THE MOST DEMANDING USER OF VLSI IN THE FUTURE. IP COMMUNITY HAS A RESPONSIBILTY TO DEFINE FUTURE CHIP DEVELOPMENT

FIGURE 8



POSSIBLE IMAGE PROCESSING CONFIGURATION

FIGURE 9

EXAMPLES OF STANDARD IP BLOCKS

ROBUST LOCAL REGION CLASSIFIERS
HEURISTIC CLASSIFIERS
TEXTURE OPERATOR
3D SHAPE INTERPRETOR
APPLICATION OF EXPERT SYSTEMS
DEVELOPM,ENT OF SPECIAL GRAMMARS & CONSTRAINTS
ASSOCIATIVE/ANALAGOUS MEMORIES
ATTENTION DIRECTING PROCESSES
MOVEMENT/OPTICAL FLOW OPERATORS
"CREATIVE" MODEL GENERATOR
ROBUST LOW LEVEL SEGMENTATION

FIGURE 10

FINAL POINTS

- IU WILL BECOME INCREASINGLY IMPORTANT IN MILITARY SYSTEMS
- UK RESEARCH IN IU SEEMS TO HAVE FALLEN BEHIND OTHER COUNTRIES
- 'CENTRES OF EXCELLENCE' AND MORE EMPHASIS AT UNIVERSITIES ARE VITAL
- WE MUST EXAMINE THE SCOPE FOR DEFINIG STANDARD FUNCTIONAL BLOCKS

FIGURE 11

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